Study on production techniques and provenance of faience beads excavated in China

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ABSTRACT

Based on the results of scanning electron microscopy (SEM) with energy dispersive X-ray spectrometry (EDX), about 20 faience beads from several cemeteries discovered since 1970 in China were studied chronologically and typologically. Faience beads excavated in China can be classified into two groups, chemically by composition, and by periods and provenance as: soda-enriched made somewhere on the route from Egypt to central China (11—10th century BCE); and potash-enriched made in China (middle Western Zhou to Eastern Zhou). According to the continuous matrix of inter particle glass (IP glass) and inner micro-structure, the difference between soda- and potash-enriched faience beads was identified, even though the IP glass was badly preserved. The faience beads with potash-enriched glaze and high copper content were in a better state of preservation than those with soda-enriched glaze because of their tight inner structure.

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1. Introduction

Faience is composed of crushed quartz or sand body with a soda—lime—silica glaze. It was produced in both Egypt and the Near East from the 4th millennium BC until the Roman period. The objects made from faience include bowls, tiles and small pieces such as amulets, beads, rings and scarabs. The two basic glaze colors were turquoise and black, which were produced by copper and manganese, respectively. Cobalt blue, manganese purple and lead antimonate yellow broadened the color range at the same time as the beginning of glass production around 1500 BC (Tite et al., 2007).

Both Vandiver (1983), and Tite et al. (1983, 1986), have confirmed the principal methods (direct application, efflorescence and cementation) for glazing faience in antiquity. They also suggested criteria for the identification of three glazing methods using scanning electron microscopy (SEM). Tite et al. (2003, 2007) have explored whether different types of plant ash were used for the production of faience, as well as whether the oxide ratios can be taken to represent the original plant ash composition. Rehren (2008) has reviewed the various factors affecting alkali and alkali earth oxides of Egyptian Faience.

In China, many beads, along with other larger objects, known as a type of "Liaozhu" (glass beads) were excavated from a number of tombs of the Western Zhou Dynasty (1046—771 BCE), and even later (Fu et al., 2006). They were often combined with jades and carnelians to form a collar-like necklace. Though they are not true glass, their surfaces are glassy. Their body is composed mostly of quartz, so they are real faience, but not glazed ceramic. Some of them do resemble Egyptian faience in overall appearance. Therefore, we describe all kinds of beads excavated in China as "Chinese Faience". The faience beads studied in this paper are those with glaze over quartz body, and do not include pigment beads made from a particulate material such as Chinese blue or purple, which do not have a glaze.

Ma et al. (2009) have listed archaeological sites in Shaanxi, Shanxi, Gansu and Henan that yielded Chinese faience beads. However, they provide chemical data for only 10 pieces. Most of these Chinese beads have a potash-enriched glaze, which indicates that most of those Chinese beads are potash-enriched glazes, distinguishing them from Egyptian faience. One exception is that Zhang and Ma (2009) also found one bead with soda-enriched glaze in Gansu, which was dated to the mid-Western Zhou period (Institute of Cultural Relics and Archaeology of Gansu Province, 2009). In that paper three samples (Sample GCYF-1, 2 &3) from the M94 in Yujiawan, Gansu (Fig. 11) were examined and only one

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(Sample GCYF-1) of them has a well-preserved soda glaze. The other two were badly preserved without any flux identified.

The published papers about Chinese faience have some limitations, leaving a key question unsolved: What is the relationship between Egyptian faience and Chinese faience, since both have similar appearance in shape or color? And why have soda-enriched beads been so rarely found in China?

The previous research efforts on Chinese faience, in our opinion, were not carried out taking typology into consideration. The small size of the beads may have led to omissions if microscopy was not employed. There may also have been some differences in shape, as well as in composition of those beads, which were not factored into the analysis.

The previous research on Chinese faience seems not to have incorporated the context in which the beads were discovered into their assessments, thus weakening the chronological studies. For example, bronzes with inscriptions buried with those beads actually provide excellent evidence for dating. If the inscriptions relate to reliable historical incidents confirmed by other historical scripts, exciting information both in terms of provenance and date might be gleaned. Furthermore, the typologies of bronzes and ceramics have been well established in China, providing additional

Table 1
Chronological assumption of the cemetery of Jin state by Li Boqian.

Tombs' number	Dates (BCE)
M114、M113	1000–925
M9、M13	935–855
M6、M7	910–845
M33、M32	880–831
M91、M92	860–816
M1、M2	834–804
M8、M31	814–796
M64、M62、M63	800–784
M93、M102	789–768

possibilities for relating beads found in context with them. Thus, the sites or tombs with those excavated bronzes could actually provide more specific dates, such as the early, middle or late Western Zhou, rather only the general period. Taken together, the differences in composition combined with the styles and shapes of the Chinese faience can help to pinpoint specific dates.

This current study examines 20 faience beads excavated from several sites in northern China since 1970 (Fig. 1).

Fig. 1. Location of the archaeological sites mentioned in the article: 1 – Yujiawan, 2 – Baoji (Rujiazhuang, Zhifangtou, Zhuyuangou), Yu state, 3 – Liangdaicun, Rui state, 4 – Tianma-Qucun, Jin state, 5 – Yangshe, Jin state, 6 – Hengshui, Peng state.

The cemetery of the Yu state (11—10th century BCE) composed of three main locations (Rujiazhuang, Zhifangtou and Zhuangyuangou) was excavated at Baoji in Shaanxi province in the 1970s. Two samples were collected from tomb BZM5, Zhuangyuangou, which was dated to early mid-Western Zhou period (Lu and Hu, 1988).

The cemetery of the Jin state is in Shanxi province near the Yellow River. The principle cemetery of the Jin state (Jinguo Mudi) is at Tianma-Qucun (The School of Archaeology and Museology, 1993, 1994a,b,c, 1995, 2001) on the north side of Fu River. Based on Li Boqian's summary paper (2002), the cemetery of the Jin state dates from 1000 to 768 BCE (Table 1). Nine samples were collected from there.

A recent excavation of a cemetery at Yangshe in Shanxi (Fig. 1) on the other side of Fu River was reported as the continuance of the cemetery at Tianma-Qucun. The date of the two biggest tombs at Yangshe, tombs M1 and M2, were assumed later than tomb M93 of Tianma-Qucun (Shanxi Provincial Institute of Archaeology, 2009). We picked five samples from the two biggest tombs.

Two sites of cemeteries were recently found on either side of Yellow River. The earlier one is in Hengshui in Jiangxian, Shanxi near Tianma-Qucun. This was the cemetery of a small state by the name of Peng (Fig. 1) (Shanxi Provincial Institute of Archaeology, 2006). The second is at Liangdaicn at Hancheng in Shaanxi province. This site is attributed to a small state, Rui (Fig. 1) (Shaanxi Provincial Institute of Archaeology, 2007a,b, 2008).

The two biggest tombs in the cemetery of Peng are tombs M1 and M2. Their date is reported close to tombs M33, M32, M91, M92 in Tianma-Qucun (Archaeology Institute of Shanxi Province, 2006). Two samples from M1 were chosen for analysis.

The cemetery of Rui dates to the 8th—7th century BCE. There are three big tombs reported briefly with several illustrations (Shaanxi Provincial Institute of Archaeology et al., 2007a,b, 2008). However, faience beads were only site found in M26 in a woman's burial. The date of the M26 is close to M93 in Tianma-Qucun (Shaanxi Provincial Institute of Archaeology et al., 2008). Two samples from M26 were studied as part of this research.

The excavations carried out at these five cemeteries revealed hundreds of faience beads, as well as inscribed bronze vessels. Though still somewhat in dispute, archaeologists have reached a general agreement on the date sequence of the tombs according to excavated bronze inscriptions and typologies. We also studied the chronology of the excavated beads based on chronological identification of those tombs.

The aim of the present study is to not only systemically study the composition and micro-structure of Chinese beads by SEM, but also provides chronological and typological interpretation. Because of corrosion, weathering of the glazes may have disturbed some of the physical evidence offered by the beads. However, the residue and inner structure still provides new and significant information.

2. Experimental procedures

2.1. Samples

The faience beads examined here are in tubular, bi-conical and spherical shapes. The examined beads are all listed in Table 2, including tomb numbers, locations and assumed sequence of date. The majority of the samples have a white body with blue or green glaze on both sides, except for one big cylinder bead with sallow body from Yangshe, Shanxi (Table 2, Fig. 2). This distinctive bead (YS_M2_2c2) was only glazed on its outer side and is 15 mm long and 3 mm thick. It is bigger than other tubular examples. Many beads were partly covered with cinnabar and clay, which may have obscured the original color of body or glaze. In addition, deep blue beads were found in tomb M92 in Tianma Qucun, cemetery in Yangshe and tomb BZM5 in Zhuyuangou. Similar deep blue beads were also found in tomb M26 in Liangdaicun, but none of these beads were obtained for this analysis.

2.2. Determination of microstructures and chemical compositions

The faience beads were first observed carefully through an optical stereomicroscope. Then small samples were cut off from the beads being studied and cast into mini-cubes of polyester resin (Technovit 2000LC, Heraeus Kulzer). The resin was allowed to cure for 30 min at room temperature and under blue light. The cubes were then ground to expose the cross-sections, and dry polished with 400 and 600 grit wet-dry papers and Micro-Mesh polishing cloths, with grits from 1500 to 12,000.

These polished sections were observed by a FEI quanta 200 FEG (FEI Company) scanning electron microscope (SEM) with energy dispersive X-ray spectrometry (EDX) to document their

Table 2
Description of beads studied.

Tomb numbers & locations	Code	Shape	Color of glaze	Color of body	General size (mm)
M5, Zhuyuangou	BZ_M5_15c	Unidentified	Blue	White	Tiny broken shreds (Incomplete)
	BZ_M5_15d	Unidentified	Blue	White	
M113, Tianma Qucun	TMQC_M113_63a	Spherical	Green	White	Spherical: 8 (diameter) or so;
	TMQC_M113_62b	Spherical	Green	White	Bi-conical:10 (width) × 10 (centre-diameter) or so;
M13, Tianma Qucun	TMQC_M13_170a	Spherical	Green	White	Tubular: 10—15 (length) × 5 (diameter) × 1 (thickness) or so;
	TMQC_M13_182a	Tubular	Green	White	Only one cylander of M2, Yangshe, (Code: YSM2_2c1):
M31, Tianma Qucun	TMQC_M31a	Spherical	Green	White	width 15 (length) × 9 (incomplete width) × 3 (thickness)
M92, Tianma Qucun	TMQC_M92_101b	Tubular	Green	White	
	TMQC_M92_101d	Tubular	Blue	White	
M1, Hengshui	HS_M1_109	Spherical	Green	White	
	HS_M1_110	Tubular	Green	White	
M63, Tianma Qucun	TMQC_M63_32a	Spherical	Green	White	
	TMQC_M63_22c	Bi-conical	Green	White	
M1, Yangshe	YS_M1_a	Bi-conical	Blue	White	
M2, Yangshe	YS_M2_1	Bi-conical	Blue	White	
	YS_M2_2b	Spherical	Green	White	
	YS_M2_2c1	Bi-conical	Green	White	
	YS_M2_2c2	Cylander	Green	Sallow	
M26, Liangdaicun	LDC_M26_1	Spherical	Green	White	
	LDC_M26_2	Tubular	Green	White	

Fig. 2. Most of the faience beads examined (description in Table 2).

microstructures. Then BSE mode was chosen for different phase identification.

The chemical compositions of the glass phases between the quartz were then determined using EDX spot analysis operated at accelerating voltage of 15 kv and emission current of about 200 μA,

Table 3
Comparison of Corning A glass standard compositions as published and as analyzed.

Oxide	As published (Brill, 1999)	As analyzed	
		Average[a]	SD
SiO_2	67.07	64.17	0.043
Na_2O	14.3	16.1	0.130
MgO	2.66	2.78	0.045
Al_2O_3	1.00	1.14	0.140
K_2O	2.87	2.68	0.066
CaO	5.03	4.33	0.139
Fe_2O_3	1.09	1.23	0.128
CuO	1.17	1.30	0.111
Total	93.73	95.19	0.802

[a] Totals are for the eight oxides analyzed. The published totals for 17 elements are 100%. The same eight elements oxides are 93.73%. The other nine elements oxides (TiO_2, Sb_2O_5, MnO, CoO, SnO_2, ZnO, BaO, SrO, P_2O_5) account for balance of 6.27%. The compositions of the nine elements oxides are too low to discuss, which might because of the poor preservation or limited examination time.

which had been calibrated using appropriate primary standards. Before and after measuring the samples, the accuracy was confirmed by the analysis of the Corning A glass standard. According to the analytical results (Table 3) for the eight elements, most relative standard deviations are less than 15%. The examples examined in this paper are badly preserved and seriously weathered, which has led to uneven loss of Na and K. Though EDX would provide only semi-quantitative data, which is not as good as wavelength-dispersive spectrometers (WDS), the major target of this research is to identify potash/soda-enriched inter particle glass and the general ratios of Na_2O and K_2O. So the EDX-data accuracy would thus meet the requirement of related data interpretation.

For some of the ancient faience, the actual glaze layer is severely weathered and they had lost most of the soda and potash. Sodium and potassium are also sometimes difficult to identify by EDX.

3. Discussion

When observing and describing faience microstructures by SEM, Tite (2007) and Vandiver (1998) used three terms: GLZ ("the essentially quartz-free glaze layer"), IAL ("the interaction layer between the glaze and body which consists of quartz embedded in a more-or-less continuous matrix of glass") and IPG ("the body itself which can contain varying amounts of interparticle glass that bonds together the quartz particles"). However, because all the samples for this current study were from archaeological sites and were weathered, no GLZ were clearly observed in any of the samples. It can also be difficult to distinguish between IAL and IPG, because it is assumed that IAL could turn to IPG in microstructure if a bead was severely weathered. So we would prefer to use IP glass to describe the "glass phases present in faience within the body, holding together the individual quartz grains" (Rehren, 2008).

3.1. Faience making

Ground quartz sands were used for making beads, identified based on the sharp edges of the particles, implying the process of deliberate grinding. Copper as the unique colorant was identified by EDX, which indicates a copper blue or green color. The EDX also identified chloride in some of these samples, but without reliable standard samples for quantitative analysis. However, the presence of chloride is likely the result of weathering/corrosion during burial.

Most of these beads have more or less IP glass preserved, including the fluxing alkali (soda or potash). When observed in the backscattered electron (BSE) mode of SEM, the IP glass with soda, potash and copper is brighter than the adjacent quartz. Based on the EDX-data, two samples (TMQC_M113_63a, TMQC_M13_182a) from tombs M113 and M13 have soda-enriched IP glass, while other beads with IP glass preserved present potash-enriched glass, which meet the different ratio of Na_2O/K_2O (Table 4). Though the composition of CoO, SnO, PbO, Sb_2O_3 and MnO are significant in Egyptian faience, they are fairly low and cannot be accurately identified in Chinese faience beads by EDX. So the data on the identification of these five elements is not well enough established to include in this discussion.

The preservation state of the beads is complex and involves two kinds of corrosion: the first is where only the flux (soda or potash) has been lost, but the structure remains preserved; and the second is structural corrosion with the loss of IP glass and quartz embedded (Table 5). The first kind does not have significant influence when identifying the glazing method, but the second may obscure the original microstructure.

Almost all the faience beads measured in this paper have double-sides glaze except for one piece (YS_M2_2c1) (Fig. 2) from

Table 4
Chemical composition (wt%) of IPG of IPG-residue of Chinese faience beads.

Code	Color of glaze	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	Fe_2O_3	CuO	Na_2O/K_2O
BZ_M5_15c	Blue	3.7	0.55	1.45	70.35	14.39	0.6		8.95	0.26
BZ_M5_15d	Blue	1.81	0.59	12.72	66.44	13.59	0.6		4.25	0.13
TMQC_M113_63a	Green	8.93	0.94	3.43	72.64	2.6	0.65	1.4	8.61	3.43
TMQC_M113_62b*	Green	0.3	0.36	4.43	83.73	0.7	1	1.42	4.84	
TMQC_M13_170a*	Green	0.81	0.42	2.18	87.98	0.53	0.69	0.9	5.29	
TMQC_M13_182a	Green	7.43	0.45	3.36	72.94	2.43	1.28	1.86	6.61	3.06
TMQC_M31a	Green	2.89	0.22	3.54	73.67	12.02	0.92		5.49	0.24
TMQC_M92_101b*	Green	0.33	0.43	1.7	91.41	0.39	0.91	1.02	2.76	
TMQC_M92_101d	Blue	3.84	0.24	0.49	69.1	13.1	0.96	1.09	10.62	0.29
HS_M1_109	Green	2.73	0.46	2.79	72.3	11.64	0.91	1.31	7.11	0.23
HS_M1_110	Green	3.45	0.44	4.6	73.45	10.58	0.5	0.69	5.95	0.33
TMQC_M63_32a	Green	0.27	0.46	3.13	87.9	0.93	0.81	0.98	4.82	
TMQC_M63_22c	Green	4.34	0.76	1.53	82.77	6.12	1.19	0.71	2.12	0.71
YS_M1_a	Blue	5.46	0.86	2.7	70.47	9.2	1.22	1.09	8.26	0.59
YS_M2_1	Blue	7.23		2.23	69.03	9.79	0.86		10.27	0.74
YS_M2_2b	Green	3.28	0.3	3.04	74.99	11.43	0.35	0.74	5.17	0.29
YS_M2_2c1	Green	4.09	0.46	2.48	71.96	12.45	1.72	0.76	5.05	0.33
YS_M2_2c2	Green	5.18	0.42	3.97	74.07	9.62	0.27	0.67	5.2	0.54
LDC_M26_1	Green	5.06	0.32	3.19	74.93	9.22	0.72		5.92	0.55
LDC_M26_2	Green			0.94	93.57		0.42		4.06	

* indicates the data of IP glass residue without soda or potash well preserved.

Table 5
The conservation status of Chinese faience beads evaluated in two kinds of corrosion.[a]

Code	The lost of flux in IP glass but with copper preserved			Structural corrosion with the lost of IP glass and quartz embedded		
	None	Close to surface level	Fully lost of flux but with copper preserved	Not significant	Partly with some IP glass reserved	Fully lost without any IP glass reserved
BZ_M5_15c	Y			Y		
BZ_M5_15d	Y				Y	
TMQC_M113_63a	Y				Y	
TMQC_M113_62b			Y			Y
TMQC_M13_170a			Y			Y
TMQC_M13_182a	Y				Y	
TMQC_M31a	Y				Y	
TMQC_M92_101b			Y			Y
TMQC_M92_101d	Y			Y		
HS_M1_109	Y				Y	
HS_M1_110	Y				Y	
TMQC_M63_32a			Y		Y	
TMQC_M63_22c		Y			Y	
YS_M1_a	Y			Y		
YS_M2_1	Y			Y		
YS_M2_2b		Y			Y	
YS_M2_2c1		Y			Y	
YS_M2_2c2		Y			Y	
LDC_M26_1	Y				Y	
LDC_M26_2			Y	Y		

[a] Y means Yes.

tomb M2 in Yangshe. Though only one third of the complete piece was preserved, the extra one-side-glazed cylinder bead is bigger than others (Table 2). The IP glass was potash-enriched (Table 4). Its glazing technique might be application. Because it is not made of IP glass, this type of faience the mechanical stability of the core material is reduced if no other technique was involved. So this glazing method only appeared when pre-fired ceramic bodies of sufficient strength were developed (Rehren, 2008). If a ceramic production technique was involved in making the piece, we cannot deny the possibility of influence from local well-developed Chinese ceramic technologies.

Most potash-enriched beads (Tale 4), especially three blue beads (BZ_M5_15c, TMQC_M92_101d, YS_M1_a) have more continuous matrixes of IP glass with quartz embedded (e.g. Fig. 3) than the soda-enriched beads (e.g. Fig. 4) in BSE. The blue beads have a higher composition of copper oxide (above 8 wt%) in IP glass than green ones (Table 4).

The IP glass in the three blue beads does not concentrate to the surface but forms an integrated and continuous glass matrix embedded quartz. Similar structure was proposed by Tite (1983) when simulating efflorescence technique. His interpretation was that the glaze components could not move to the surface without enough water, which led to significant amounts of glass produced in the cores of the beads. So the three blue beads were made by incomplete efflorescence. Though surface level is a little bit corroded, incomplete efflorescence was also identified for a green bead (Fig. 5).
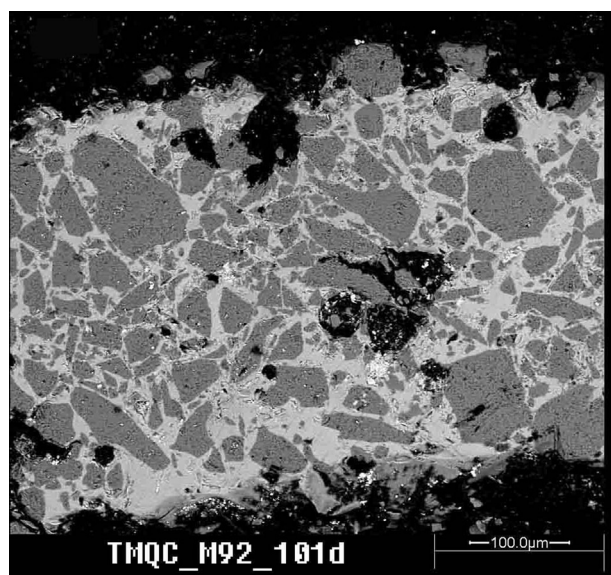

Fig. 3. The BSE image of sample TMQC_M92_101d from M92 in Tianma-Qucun, Shanxi. An integrated and continuous matrix of IP glass with quartz embedded indicates incomplete efflorescence.
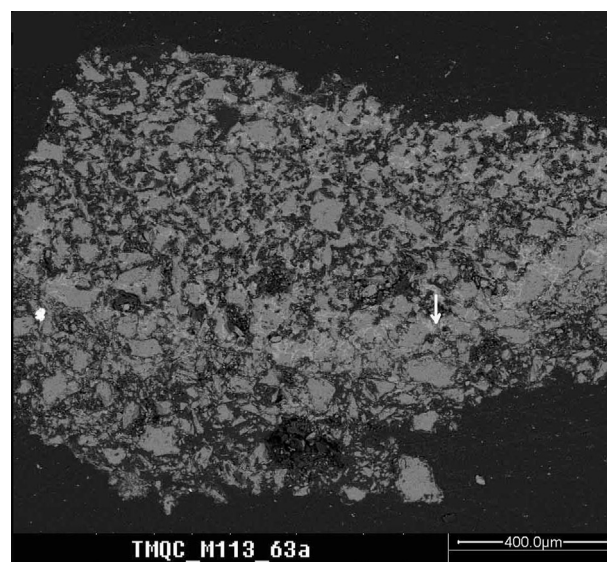

Fig. 4. The BSE image of sample TMQC_M113_63a from M113 in Tianma-Qucun, Shanxi. A continuous matrix of IP glass (an arrow mark) concentrated at the surface (down).
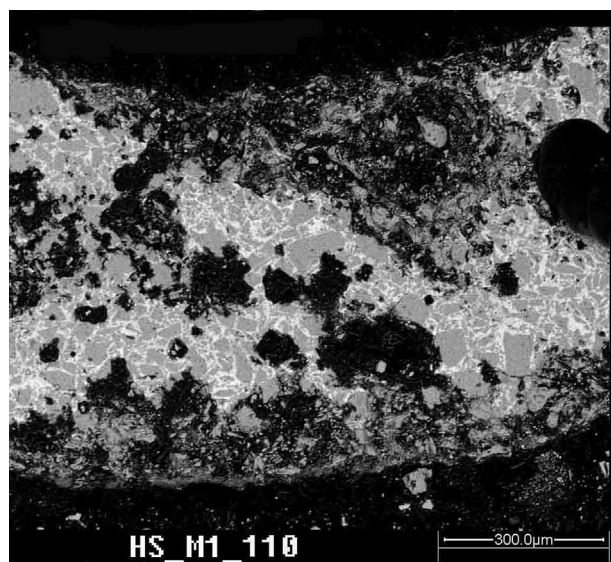
Fig. 5. The BSE image of (green) sample HS_M1_110 from M1 in Hengshui, Shanxi. The continuous matrix of IP glass almost fully spread through the section indicates efflorescence. The surface level was weathered and partly corroded.
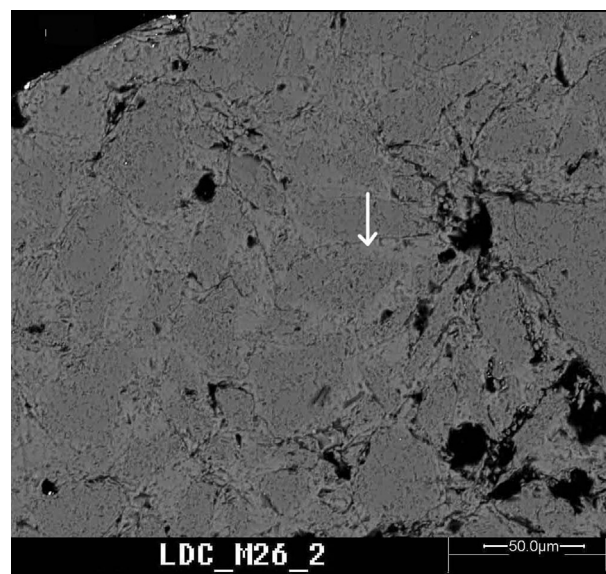

Fig. 7. The BSE image of sample LDC_M26_2 from M26 in Liangdaicun, Shaanxi. The weathered IP glass has copper (bright strips with an arrow mark) rather than flux preserved. The integrated microstructure indicates incomplete efflorescence.

For the beads glazed by efflorescence, Tite (1983) observed the concentration of the glass phase towards the surface, as well as other two characteristics of the microstructure. The first is related to the outer glaze, which unfortunately was poorly preserved in the beads studied; the second is related to the difficulty of distinguishing the continuous matrix of glass from quartz cores, because the latter also contains extensive interstitial glass. The samples with well-preserved glass, such as samples YS_M2_1 (Fig. 6) and the four beads mentioned above, meet the second characteristic and the IP glass concentrates on the surface. But the rest of samples are quite weathered, which complicates interpretation.

Though some beads (e.g. samples LDC_M26_2 and TMQC_M63_32a) were not well preserved because of the loss of

most of the soda and potash (Table 4), the range of IP glass could be indicated by the residue of copper based on the brighter BSE images than quartz (Figs. 7 and 8). These types of weathered beads actually have their microstructure partly preserved. The residue of IP glass of the two samples indicates incomplete efflorescence.

It was intriguing to find both the weathered IP glass (without potash and soda but copper preserved) near the surface and the better preserved IP glass below in the BSE images of four samples (TMQC_M63_22c, YS_M2_2b, YS_M2_2c2) (e.g. Fig. 9), which indicates the ongoing loss of flux. It is not a stretch to infer that the surface preservation was caused by the environmental conditions, which has led to the lower contents of potash and soda in the surface compared to the body. Thus the IP glass and its residue with
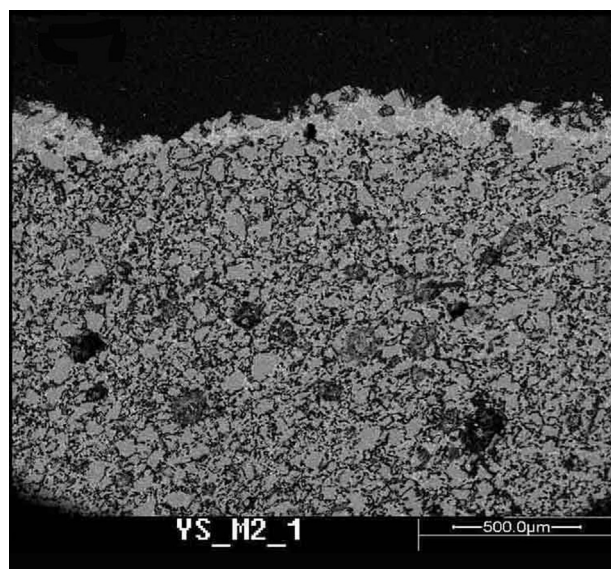

Fig. 6. The BSE image of sample YS_M2_1 from M2 in Yangshe, Shanxi. Both of the continuous matrixes of glass (bright strips on top) concentrates at the surface and the unclear quartz core indicate efflorescence.
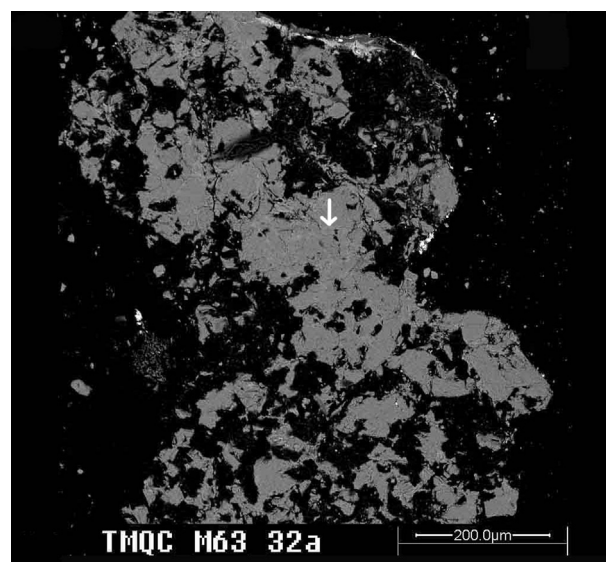

Fig. 8. The BSE image of sample TMQC_M63_32a from M63 in Tianma-Qucun, Shanxi. Though flux was lost, the bright residue of continuous IP glass (an arrow mark) spreads to the upper section. The concentration of IP glass and unclear quartz core indicate efflorescence.
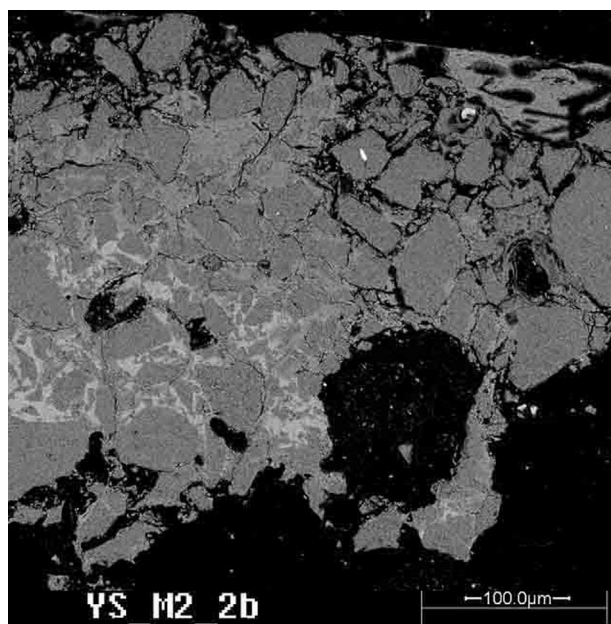
Fig. 9. The BSE image of sample YS_M2_2b from M2 in Yangshe, Shanxi. Both the compact IP glass (bright, down level) and its residue (light gray, up level) indicate incomplete efflorescence.

adjacent quartz are still present their original microstructure. So the evidence in these four samples actually indicates efflorescence.

All of the four potash-enriched samples (BZ_M5_15d, TMQC_M31a, HS_M1_109, LDC_M26_1) (e.g. Fig. 10) and the two soda-enriched samples (TMQC_M113_63a and TMQC_M13_182a) (e.g. Fig. 4) have IP glass preserved in the central core but lost at the surface. The concentration of the glass phase, as well as unclear quartz core in these samples, meets the microstructural criteria of efflorescence proposed by Tite (1983).

Because of the serious weathering, the soda and potash of the samples (TMQC_M113_62b, TMQC_M13_170a, TMQC_M92_101b) are poorly preserved with contents less than 1wt%. However, we

Fig. 11. The BSE image of sample TMQC_M113_62b from M113 in Tianma-Qucun, Shanxi. The weathered bead barely has any IP glass preserved, but it has a porous inner microstructure.

can infer that the two beads (TMQC_M113_62b, TMQC_M13_170a) from tombs M113 and M13 in Tianma-Qucun, have more porous inner structures (e.g. Fig. 11) than the sample TMQC_M92_101b (Fig. 12). In other words, sample TMQC_M92_101b, though badly preserved with most of the flux lost, still retains a tight inner microstructure. The methods of glazing for the three samples are complicated and will be discussed later.

The faience studied by Tite was soda-enriched objects. The potash-enriched beads in this paper have some other characteristics which require further discussion.

In reference to Tite (Tite et al., 2007), Rehren (2008) emphasizes a key point regarding efflorescence. He notes: "… most soda compounds are fairly easy to dry in a sunny Egyptian climate, potash compounds are much more hygroscopic and often deliquescent, making it impossible to dry them under normal
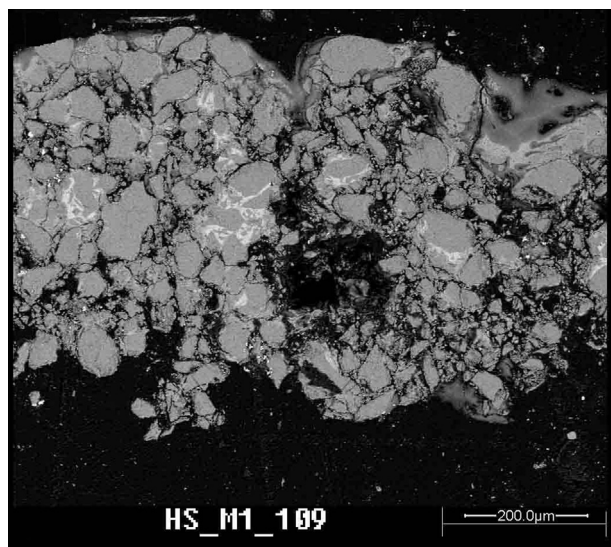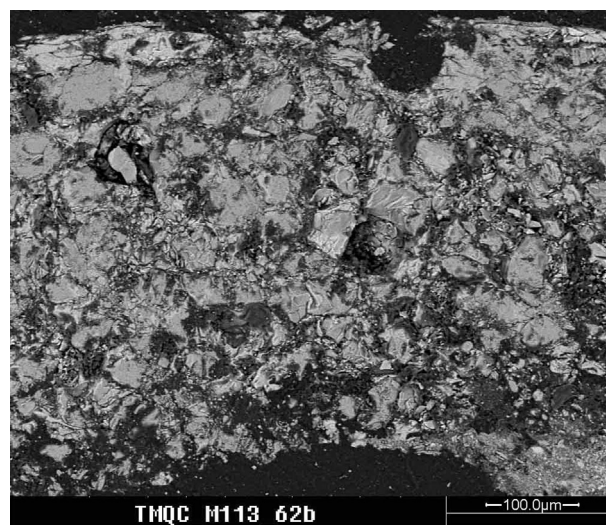

Fig. 10. The BSE image of sample HS_M1_109 from M1 in Hengshui, Shanxi. Both the bright integrated IP glass in middle level, as well as unclear quartz core indicates efflorescence. The surface level is corroded with some loss of IP glass.
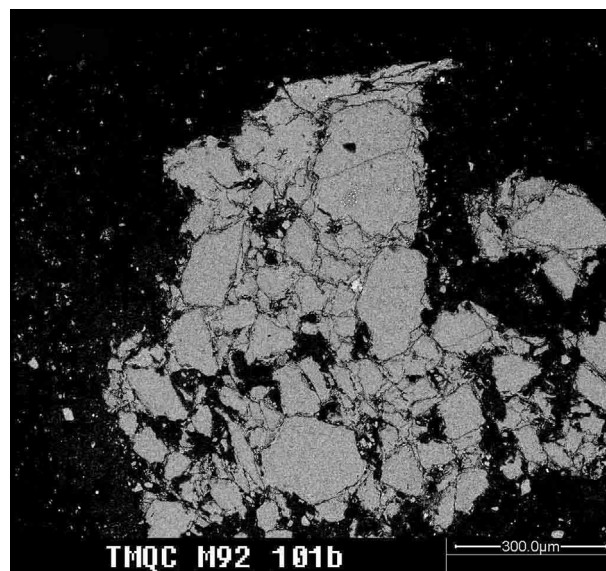

Fig. 12. The BSE image of sample TMQC_M92_101b from M92 in Tianma-Qucun, Shanxi. The weathered beads hardly have any IP glass or residue identified preserved, but its quartz is tightly concentrated.

conditions. Thus, soda is likely to partition preferentially into the efflorescent crust and hence the faience glaze, while the remaining moisture, enriched in potash salts, will remain evenly distributed throughout the body, leading to the formation of potash-enriched IP glass".

It is more difficult for soda to concentrate in the body than on the surface, which means that soda-enriched faience has a more open and porous inner structure than potash-enriched faience. This suggests that some potash-enriched beads only have the microstructure of IAL, but without any IPG, which typically might result in more incomplete efflorescence.

Faience beads of the tombs M113 and M13 (Tianma Qucun) are badly preserved. There are no surface glaze extant. However, it was found that some of these beads still have a more-or-less continuous matrix of soda glass (e.g. Fig. 4, Table 4). The IP glass with the more open and porous structure is typical of soda-enriched faience, though the soda-shell-glaze was not preserved. So if the IP glass is not well preserved, it is possible to determine that the other two beads (M113_62b and M13_170a) might be also made by efflorescence with soda-enriched ash. This is due to their more loose inner structure (e.g. Fig. 11) compared to most of other potash-enriched beads.

The BSE images of potash-enriched beads (e.g. Figs. 3, 5–10) present different inner microstructures compared soda-enriched ones (e.g. Figs. 4 and 11). They have more continuous matrix of IP glass. Based on the finding that potash-enriched faience has a tighter inner structure, potash-enriched IP glass and efflorescence can be confirmed for the beads with rich potassium content and tight micro-structure, even without potash preserved (e.g. Fig. 12). One specific sample (Fig. 6) has lower ratio of NaO/K_2O of IP glass similar to 1, which leads to a slightly looser inner structure than that of other potash-enriched samples.

Based on the character of inner structure, the former paper of Zhang and Ma (2009) can be reinterpreted. Among the three samples, only one (Sample GCYF-1) has preserved soda; the porous inner structure of all the three samples (Sample GCYF-2 &3) actually imply the glazing technique of efflorescence with soda-enriched ash (Fig. 13).

GCYF_1 indicates bright soda-enriched IP glass with tight structure to the left side; GCYF_2 and 3 imply the loss of flux, but with tight IP glass structure preserved on outer side or both sides. The loose IP glass structures imply that the efflorescence glazing method was used with soda-enriched ash.

Tite and Shortland have explained (2003) why the composition of MgO is low in Egyptian faiences. They mention a specific plant ash, which is low in magnesia but high in potassium in Egypt, which could be the material for making glaze. A similar type of plant might also have been used for making the two Chinese

faience samples (TMQC_M113_63a and TMQC_M13_182a), which led to the low component of MgO (Table 4). However, the two samples also have a 3% level of alumina in IP glass, which is much higher than Egyptian faience beads with 1.5% level. The reason may be that the two Chinese samples have more feldspar mixed in.

Thus for the faience beads excavated in China, both of the two soda-enriched faience beads and most of potash-enriched faience beads (except for sample studied), seemed be made by efflorescence method, based on the characteristics of the microstructure in BSE images. Even though flux (soda and potash) have been almost lost, if the microstructure could be sufficiently identified based on the residue, the method of production can be logically deduced. Even if the beads without any IP glass or even clear residue (bright images in BSE) preserved, the tight microstructure probably indicates potash-enriched beads made by efflorescence, the relative porous microstructure imply the soda-enriched beads, as well as the method of efflorescence.

3.2. Provenance study

3.2.1. Egyptian influence

Compared with the data of Tite et al. (2007), the examples from M113 and M13 (Tiangma Qucun) show a similar ratio of Na_2O/K_2O (about 3) in IP glass, which is similar to Middle Kingdom-Second Intermediate Period Abydos and Amarna faience. By the means above suggested by Rehren (2008), we assumed that the beads of the tree tombs were made from soda-enriched ash with efflorescence.

This suggests that central China had some materials or techniques connected with Egypt or other regions influenced by Egyptian faience production technology around 3000 years ago. Though I prefer the direct influence from Egypt, the possibility of influences from other areas in west, middle Asia on the route to China, or even in China, cannot be denied.

The authors have done situ investigation and researched the related archaeological reports of all the tombs sampled above. The tombs other than M113, M13 (Tianma Qucun) and M94 (Yujiawan) (Cultural Relics team of Gansu province, 1986) have excavated the bi-conical beads, which meets the ratio difference of Na_2O/K_2O between them (>1 and <1).

The composition and ratio difference of Na_2O/K_2O between those three early tombs (tombs M113 and M13 at Tiangma Qucun, and tomb M94 at Yujiawan) and other tombs (M5 at Zhuyuangou, M92, M31 and M63 at Tianma Qucun, M1 at Hengshui, M1 and M2 at Yangshe, M26 at Liangdaicun) indicate the difference of technique as well as provenance.

Some beads might be inherited from elder generations, so the dates of specific tombs may not clearly indicate the times when those beads were made. Thus we can only generally assume the
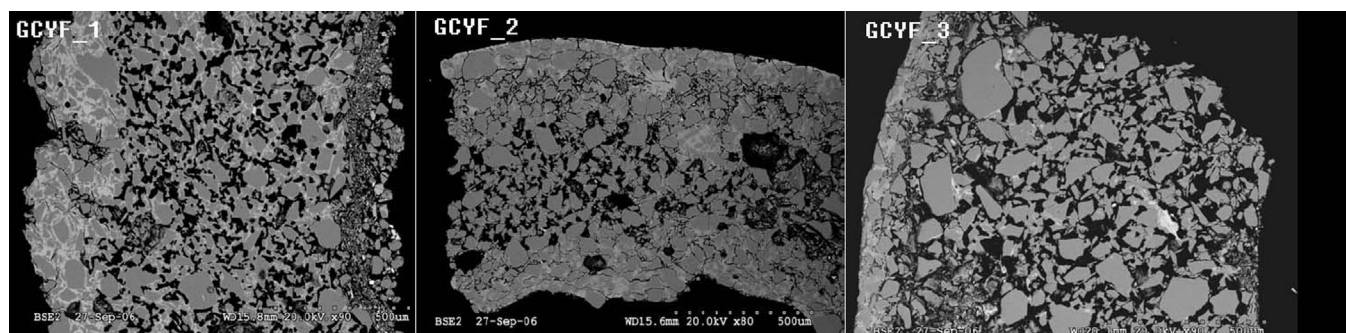

Fig. 13. Cross sections by SEM of soda-enriched faience beads from the cemetery in Tomb M94 Yujiawan, Gansu, Zhang and Ma (2009).

introduction of techniques using high potash beads in China was in the 10th century BCE.

3.2.2. Mesopotamian influence and Chinese technique

Jessica Rawson (2010) has summarized the four major or different phases of contact between Chinese speakers and peoples, according to artifacts and ornament types found in China. Her opinion provided a great deal evidence for the provenance study on Chinese faience beads. The first period (1300–1000 BCE) from the later Shang to Early Western Zhou periods was identified by "… borrowings of mirrors, knives and chariots. Towards the end of this phase, striking figures of realistic creatures were incorporated in bronze ritual vessel design, probably as a result of interaction with peoples to the north and west." The cemeteries of Yu state were put into the late part of the first period.

The second period from the early Western Zhou down to the early Eastern Zhou (1000–650 BCE) is "… the period of carnelian beads, alongside which animal figures and interlaced ornament were deployed on weapons, chariot fittings and Vessels, and new vessel types, gold and iron were introduced." She also emphasized that the bi-conical shape of carnelian and faience beads in this second period were influenced by Mesopotamia.

The faience beads studied have been classified as two groups by composition and ratio of Na_2O/K_2O, which is similar to Rawson's theory. Faience beads have not been found in Shang period. The soda-enriched beads from the tombs at Tianma Qucun and Yujiawan belong to the early group, which might have been made in Egypt or somewhere on the way to Central China. The potash-enriched and bi-conical bead faience beads from the tombs (M31, M92 and M63 in Tianma Qucun, M26 in Liangdaicun) might have influences from Mesopotamia in their shape.

However, we cannot find similar chemical composition data for Mesopotamian faience. Some workshops influenced by Mesopotamian decorative arts might have made those potash enriched beads. Though it is still difficult to confirm whether they were Mesopotamian-made, or Chinese-made beads, some evidence might support the latter.

Potash-enriched glaze of Chinese faience has low proportion of MgO, does not deny the possibility of using plant ash for glaze making (Freestone et al., 2003). When moving to even later period of Eastern Zhou (770–221 BCE), the low MgO is a continuous compositional character of potash-enriched glass and eye beads. So it appears that those beads were made from the same kind of flux, nitre (Zhao Kuanghua, 1991).

Fig. 14. Tubular beads with raised decoration from M26 of Liangdaicun, provided by Sun Bingjun.

Nitre is the mineral form of potassium nitrate, KNO_3. Nitre used as a natural medicine has been documented in the later half of the Eastern Zhou on a silk script excavated from a Western Han noble's tomb (206 BC–24 AD) (Zhao Kuanghua, 1991). It was also a popular material for making the pill of immortality mentioned in several medical scripts (Meng Naichang, 1990). Also, nitre could have been used as a distinct flux for making Chinese faience in the Western Zhou period and glass-making in the Eastern Zhou period. Thus, Chinese faience with potash-enriched character and low MgO glaze might be Chinese local products, and the Western Zhou period is the introductory period for those distinct glaze or glass artifacts. In addition, the nitre material might also have slowed the speed at which craftspeople adopted the technique of glass making. For example, the technique of making Chinese faience production was not learned by the craftsmen in the Rui state, because there are a great number of ceramic beads without glaze excavated in a tomb of Liandaicun.

Jessica Rawson's hypothesis (2010) about communication between the west and China is consistent with the similarity of the composition of Egyptian and Chinese faiences. Rawson's separation between the first and second periods appears to be coincident with the initial production of (10th century) of high potassium and bi-conical faience beads in China.

Rawson (2010) also put the cemetery of the Yu state into the first period and the cemetery of the Jin state into the second period. However, tomb M5 in Zhuyuangou (a late tomb in the cemetery of Yu state) has two potash-enriched faience beads, while tombs M113 and M13 at Tianma Qucun (two earliest tombs in the cemetery of the Jin state) have two soda-enriched faience beads, as discussed above.

For the research on faience beads and related objects from the cemetery of the Jin state, tombs M113 and M13 might be studied as a separate group from other tombs in Tianma Qucun. That is to say, the faience beads of Jin state might have two different provenances.

Several faience beads were discovered in the cemetery of the Yu state. Tomb M5 studied at Zhuyuangou belongs to a relatively late period based on the typology of ceramics. So the faience beads from early tombs of the Yu cemetery need further analysis.

Though M94 in Yujiawan is dated to mid-Western Zhou period, its faience beads are similar in composition to two early-Western Zhou tombs. One explanation is that the faience beads from M94 were recycled and inherited from earlier generations.

In addition, it is also important to mention two other interesting pieces of evidence. A number of the ceramic bi-conical beads were excavated from tombs M19 and M27 in Liangdaicun, which implies that the technique of faience bead making was not learned by normal Chinese craftsmen. They could only imitate the shape, not glazing technique. And both of the ceramic faience beads from tomb M2 in Yangshe, and the tubular beads with raised decoration from tomb M26 (Fig. 14) at Liangdaicun, indicate a distinctive technique involved in making faience beads in early Eastern Zhou period.

4. Conclusion

1. The faience beads excavated in China can be classified into two groups based on their dates, composition and provenance. The first group is soda-enriched in composition and was made in Egypt or somewhere on the route to China from the West. So central China might have some material or production technique connection with Egypt, or regions influenced by Egyptian technology, around 3000 years ago. It spanned the early Western Zhou period (11–10th century BCE) or even later.

2. The second group is potash-enriched faience beads, especially the bi-conical and blue type (though stylistically under the

influence of Mesopotamia), might be Chinese-made beads. Nitre was involved as flux in making these beads, which was a distinctive technique of Chinese-made beads, but lower (<1 wt %) in MgO compositionally. The period of second group lasted from the middle Western Zhou (10th BCE) to Eastern Zhou. The period also involved a technique of pre-fired ceramic bodies, which was not popular for bead-making in the Western Zhou period. These two techniques are distinctly different from Egyptian faience and indicate the process of imported products, imitation or localization between China and the West. The potash-enriched glasses excavated in China were also local products.

3 Weathered faience beads often lost flux (potassium and sodium), but have copper and structure preserved, which is significant for technology and provenance research. Based on the continuous matrix of IP glass (or residue), the difference between soda- and potash-enriched faience beads was generally identified, even the IP glass was not preserved. Typically, the big continuing matrix of IP glass indicates potash-enriched glaze, while the soda-enriched glaze implies the inner porous structure.

4 Potash-enriched glazes were found to be better preserved and have more IP glass, as well as tighter inner structure, than the soda-enriched ones.

Acknowledgments

References

Archaeology Institute of Shanxi Province, 2006. A brief excavation report on the tombs of the Western Zhou located at Hengshui Town, Jiang County, Shanxi Province. Wenwu (Cult. Relics) 1, 4—18 (in Chinese).

Brill, R.H., 1999. Chemical Analysis of Early Glass. In: Appendix D: Reference Glasses (Recommended Compositions), vol. 2, p. 540.

Cultural Relics team of Gansu province, 1986. The briefing on the tomb of the Zhou Dynasty excavated from Yu Jia-wan of Chongxin county in Gansu province. Archeol. Cult. Relics 1, 1—7 (in Chinese).

Freestone, I.C., Leslie, K.A., Thirlwall, M., et al., 2003. Strontium isotopes in the Investigation of Early Glass Production: Byzantine and Early Islamic Glass from the Near East. Archaeometry 45, 19—32.

Fu, X., Gan, F., 2006. Chinese Faience and Frit. J. Chinese Ceram. Soc. 34 (4), 427—431.

Institute of Cultural Relics and Archaeology of Gansu Province, 2009. Zhou Tombs at Yujiawan Village, Chongxin County. Cultural Relics Press, p. 141.

Li, B., 2002. On excavation and study of the Jin cemetery. In: Proceedings of the Symposium on Bronzes from the Cemetery of Maquises of Jin (in Chinese). Shanghai Museum, Shanghai Fine Arts Publisher, pp. 29—40.

Lu, L., Hu, Z., 1988. The Cemetery of the Yu State in Baoji. Cultural Relics Press, Beijing, p. 16.

Ma, Q., 2009. The Research Review of Chinese Blue and Chinese Purple. In: Scientific and Technological Research on Cultural Heritage, vol. 6. Science Publishing House, Beijing, pp. 64—76 (in Chinese).

Meng, N., 1990. Reviewing the historical scripts of making pill of immortality (supplement). Relig. Stud. 2, 1—19.

Rawson, J., 2010. Carnelian Beads, Animal Figures and Exotic Vessels: Traces of Contact Between the Chinese States and Inner Asia, c. 1000—650 BC. In: Archäologie in China, vol. 1. Bridging Eurasia, pp. 1—42.

Rehren, Th, 2008. A review of factors affecting the composition of early Egyptian glasses and faience: alkali and alkali earth oxides. J. Archaeol. Sci. 35, 1345—1354.

Shaanxi Provincial Institute of Archaeology, Weinan Municipal institute of Archaeology and Preseravtion of Cultural Relics, Hancheng Municipal Bureau of Heritage and Tourism, 2007a. The brief excavation of M19 at Liangdaicun, Hancheng City, Shaanxi. Kaogu yu Wenwu (Archaeol. Cult. Relics) 2, 3—14 (in Chinese).

Shaanxi Provincial Institute of Archaeology, Weinan Municipal institute of Archaeology and Preseravtion of Cultural Relics, Hancheng Municipal Bureau of Heritage and Tourism, 2007b. The brief Excavation of M27 at Liangdaicun, Hancheng City, Shaanxi. Kaogu yu Wenwu (Archaeol. Cult. Relics) 6, 3—22 (in Chinese).

Shaanxi Provincial Institute of Archaeology, Weinan Municipal institute of Archaeology and Preseravtion of Cultural Relics, Hancheng Municipal Bureau of Heritage and Tourism, 2008. A brief Excavation Report on the No. 26 Tomb Located in Liangdai Village, Hancheng City, Shaanxi. Wen Wu (Cult. Relics) 1, 4—21 (in Chinese).

Shanxi Provincial Institute of Archaeology & Quwo Bureau of Culture relics, 2009. Yangshe Cemetery of the Jin Marquis in Quwo, Shanxi. Wenwu (Cult. Relics) 1, 4—26 (in Chinese).

The School of Archaeology and Museology, Beijing University, The Institute of Archaeology of Shanxi Province, 1993. The Spring Excavation, 1992 of the Graveyard of Marquis of Jin at the Tianma-Qucun Site. Wenwu (Cult. Relics) 3, 11—30 (in Chinese).

The School of Archaeology and Museology,Beijing University, The Institute of Archaeology of Shanxi Province, 1994a. The 2th Season of Excavation of the Graveyard of Marquis of Jin at the Tianma-Qucun Site. Wenwu (Cult. Relics) 1, 4—28 (in Chinese).

The School of Archaeology and Museology, Beijing University, The Institute of Archaeology of Shanxi Province, 1994b. The 3th Season of Excavation of the Graveyard of Marquis of Jin at the Tianma-Qucun Site. Wenwu (Cult. Relics) 8, 22—33 (in Chinese) 68.

The School of Archaeology and Museology, Beijing University, The Institute of Archaeology of Shanxi Province, 1994c. The 4th Season of Excavation of the Graveyard of Marquis of Jin at the Tianma-Qucun Site. Wenwu (Cult. Relics) 8, 4—21 (in Chinese).

The School of Archaeology and Museology, Beijing University, The Institute of Archaeology of Shanxi Province, 1995. The 5th Season of Excavation of the Graveyard of Marquis of Jin at the Tianma-Qucun Site. Wenwu (Cult. Relics) 7, 4—39 (in Chinese).

The School of Archaeology and Museology, Beijing University, The Institute of Archaeology of Shanxi Province, 2001. The 6th Season of Excavation of the Graveyard of Marquis of Jin at the Tianma-Qucun Site. Wenwu (Cult. Relics) 8, 4—21 (in Chinese).

Tite, M.S., Bimson, M., 1986. Faience: an investigation of the microstructures associated with the different methods of glazing. Archaeometry 28, 69—78.

Tite, M.S., Shortland, A.J., 2003. Production technology for copper- and cobalt-blue vitreous materials from the New Kingdom site of Amarna e a reappraisal. Archaeometry 45, 285—312.

Tite, M.S., Freestone, I.C., Bimson, M., 1983. Egyptian faience: an investigation of the methods of production. Archaeometry 25, 17—27.

Tite, M.S., Manti, P., Shortland, A.J., 2007. A technological study of ancient faience from Egypt. J. Archaeol. Sci. 34, 1568—1583.

Vandiver, P.B., 1983. Egyptian faience technology. Appendix A. In: Kaczmarczyk, A., Hedges, R.E.M. (Eds.), Ancient Egyptian Faience. Aris and Phillips, Warminster, pp. A1—A144.

Vandiver, P.B., 1998. A review and proposal of new criteria for production technologies of Egyptian faience. In: Colinart, S., Menu, M. (Eds.), La Couleur dans le Peinture et l'Emaillage de 'Egypte Ancienne. Edipuglia, Bari, pp. 121—139.

Zhang, Z., Ma, Q., 2009. Faience Beads of the Wester Zhou Dynasty Excavated in Gansu Province, China: a Technical Study. In: Ancient Glass Research along the Silk Road. World Scientific Publishing Company, pp. 275—289.

Zhao, K., 1991. On the origin and development of traditional Chinese glass. Stud. Hist. Nat. Sci. 10 (2), 145—156.